A GIS-based Suitability Analysis of Xiamen's Green Space in Park for Earthquake Disaster Prevention and Refuge

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Abstract

As an important part of the urban ecosystem, the green space in park, not only provides space for entertainment, relaxation, a public forum for exchanging ideas, as well as improving the urban ecological quality; it also plays an important role in disaster prevention. Based on the principles of unified planning, principles such as the integrating daily activity with disaster prevention and promoting proximity evacuation, this article checks the rationality of using the green space in park as earthquake refuge shelters in Xiamen city, Fujian Province, PRC. This paper seeks to develop a suitability assessment system of earthquake shelters with suitable evaluation indexes. GIS, Gray correlation, and entropy methods have been used to access the usability of t*he green space in par*k as earthquake refuge areas. Finally, some pieces of constructive advices on how to improve the usability of the green space in park as earthquake refuge areas are provided.

Keywords

Green Space in Park; Earthquake Disaster Prevention and Refuge; Suitability Assessment; GIS; Xiamen

Introduction

The green space in urban park is an important component of the urban ecosystem. These amenities play a part in regulating climate, conserving water, purifying the air, and protecting biodiversity. They also provide space for leisure and recreation. Due to the disaster events of recent years, the green space in park has served the function of sanctuary. This functionality in particular is providing more attention to these spaces. There is a need to assess the suitability of using the green space in park as earthquake refuge areas. Through the selection of appropriate assessment method, analyzing and optimizing the suitability of the green space in park as an evacuation shelter can ensure that appropriate spaces are used to their utmost potential. GIS based spatial analysis can quickly and accurately collect, integrate, and analyze spatial data and is widely available and used in urban planning(Kakumoto, Kosugi et al. 2002). Using GIS, this paper presented a method on how to assess the suitability for using the green space in park as shelter areas in Xiamen. The method developed in this paper can be further applied in other cities and areas with similar socioeconomic status.

Earthquake Disaster Prevention and Refuge Suitability Assessment System

The Selection of Evaluation Indicators

Through the study of foreign disaster prevention(Perry, Lindell et al. 1981; Lucien 2007; George, Jane et al. 2010), park planning standards, and combined with the seismic refuge shelter planning principle(GB50413 2007; GB21734 2008), a reasonable evacuation shelter should have several criteria as follows (FIG. 1):

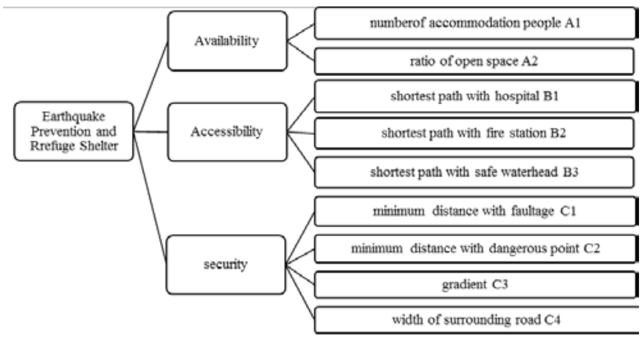


FIG. 1 SYSTEM OF SUITABILITY ASSESSMENT

a) Availability: As the shock shelter, its supply capability should be considered firstly. Shock shelters should provide enough open space to accommodate an appropriate refuge population. In addition to this property, a useful area needs to be protected from water, and away from the threat of neighboring building collapse area after earthquake. Therefore, we

will use the accommodated population and effective area ratio as availability evaluation index.

b) Accessibility: Convenient links between evacuation shelter and outside area would improve evacuation efficiency, additionally links with disaster prevention subsystem such as hospitals, fire stations, etc., can effectively reduce the loss of life. So the shortest path between evacuation shelter and hospital, fire station, and a potable water source will also be selected.

c) Security: Only in places that provide safe built environments, can refuge activities be organized and managed effectively. According to this criterion, we selected the minimum distance to faultage, dangerous points, gradient, and the width of surrounding roads as evaluation indexes.

To conclude, considering the concept of earthquake disaster reduction and refuge, the assessment system mainly includes these three categories with nine indexes in total.

Assessment Methods

1) ***Gray Correlation Method***

Comprehensive assessment will be generated through analyzing and comparing the availability, accessibility, and security of each shelter. Gray correlation is a method of multi-criteria decision that produces a pros and cons analysis about schemes and deal things according to the uncertainty. So under the actual investigation and GIS analysis(Cheng 1999), the method can be used for suitability assessment.

The effectiveness of shelter as an example, suppose the quantity of green space in park to be assessed is m, assessment indexes include n components, then constitute a decision matrix$Xm\times n$:

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} & X_{14} & X_{15} & \cdots & X_{1n} \\ X_{21} & X_{22} & X_{23} & X_{24} & X_{25} & \cdots & X_{2n} \\ X_{31} & X_{32} & X_{33} & X_{34} & X_{35} & \cdots & X_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ X_{1n} & X_{2n} & X_{3n} & X_{4n} & X_{5n} & \cdots & X_{mn} \end{bmatrix}$$

a) Because of the different index of different units, the data is normalized.

Positive type, that is the higher the index value is, the better the results are, is processed as:

$r_{ij} = \frac{x_{ij}}{maxx_j}$; Where: i=1,2,3…….m, and j=1,2,3……n

Negative type, that is the lower the index value is, the better the results are, is processed as:

$r_{ij} = \frac{minx_j}{x_{ij}}$; Where: i=1,2,3…….m, and j=1,2,3……n

In the formula: x_{ij} represents eigenvalue of index jof park green space i, $maxx_j$ and $minx_j$ is the optimal effect of the index. Then the relative membership degree r_{ij} generates a matrix:

$$R=(r_{ij})_{mxn}=\begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} & \cdots & r_{1n} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} & \cdots & r_{2n} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} & \cdots & r_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ r_{m1} & r_{m2} & r_{m3} & r_{m4} & r_{m5} & \cdots & r_{mn} \end{bmatrix}$$

b) Generates correlation coefficient l_{ij} according to the relative membership degree matrix:

$l_{ij} = \frac{\Delta Min+p.\Delta Max}{\Delta_{ij}+p.\Delta Max}$, Where: i=1,2,3…….m, and j=1,2,3……n

In the formula:

$\Delta_{ij}= |r_{ij} - Y_j|$;

$\Delta Min=Min_i\, Min_j|x_{ij} - Y_j|$;

$\Delta Max=Max_i\, Max_j|x_{ij} - Y_j|$.

Here, Yj belongs to a reference sequence Y0 consisting of the normalized relative optimal indexes; P is resolution ratio between [0 , 1],andthe value as set to be 0.5

c)Then comprehensive measure of the green space in park will be generated:

$S_{ij}=\sum_{j=1}^{n} \alpha_j l_{ij}$, Where: i=1,2,3…….m,and j=1,2,3……n

In the formula:α_j is the weighting value of index j in the assessment.

2) Entropy Method

In the use of a decision matrix, if it is not equally important between the indexes, weighted processing is needed. Compared with other methods of weighing, this paper chooses information entropy of objective weighting method to determine the weight so that to make weight more scientific and reasonable(Wang and Zhang 2001). Determining the weight of the specific method is as follows:

a) The information entropy of index j is:

$e_j = -k \sum_{i=1}^{m} \rho_{ij} ln\rho_{ij}$, Where:i=1,2,3…….m,andj=1,2,3……n

In the formula:k is positive integer, and k=1/lnm;$\rho_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$

b)The diversity index of index j is：$g_j = 1 - e_j$

c)The weight of index j is：$\alpha_j = \frac{g_j}{\sum_{j=1}^{n} g_j}$

Combining the gray correlation method and the entropy method, a generate decision valueS_i will be generated. The author will be able to carry out the assessment analysis based on this decision value.

Suitability Assessment of Xiamen Park Green for Earthquake Prevention and Refuge

General Information of Xiamen

Xiamen is located in the coastal areas, and the domestic terrain is complex and located in the middle of the earthquake zone of the southeast coast in Fujian province. It has suffered several destructiveearthquakes in history. Based on the principle of “earthquake prevention combination”, Xiamen is planning 42 evacuation shelters (Specific distribution see TABLE 1).

Establish Indicators Database

The Chinese Urban Planning and Construction codes requires the average refuge shelter per capita is at least 2m^2.Based on this standard this study calculated accommodation people and ratio of open space. Eighteen level two or above hospitals were selected. Network analyst of GIS to generate the shortest path between shelter and hospital, and employing the same approach to generate the shortest path of fire station and safe water source (FIG. 2a). The distance between shelter and dangerous point is an important safety concern, which represents higher security values. This study selected 33 dangerous points and generated a 1000m airline buffer around these points in GIS to produce the data of minimum distance to dangerous point. The same approach can produce the data of faultage (FIG. 2b). In accordance with the urban planning and construction code, the gradient of shelter is not larger than 7°, the flatter the better. Xiamen terrain TIF data was collected and used with 3D analyst in GIS to generate gradient data (FIG. 2c).

Suitability Assessment

1) Gray Correlation Model

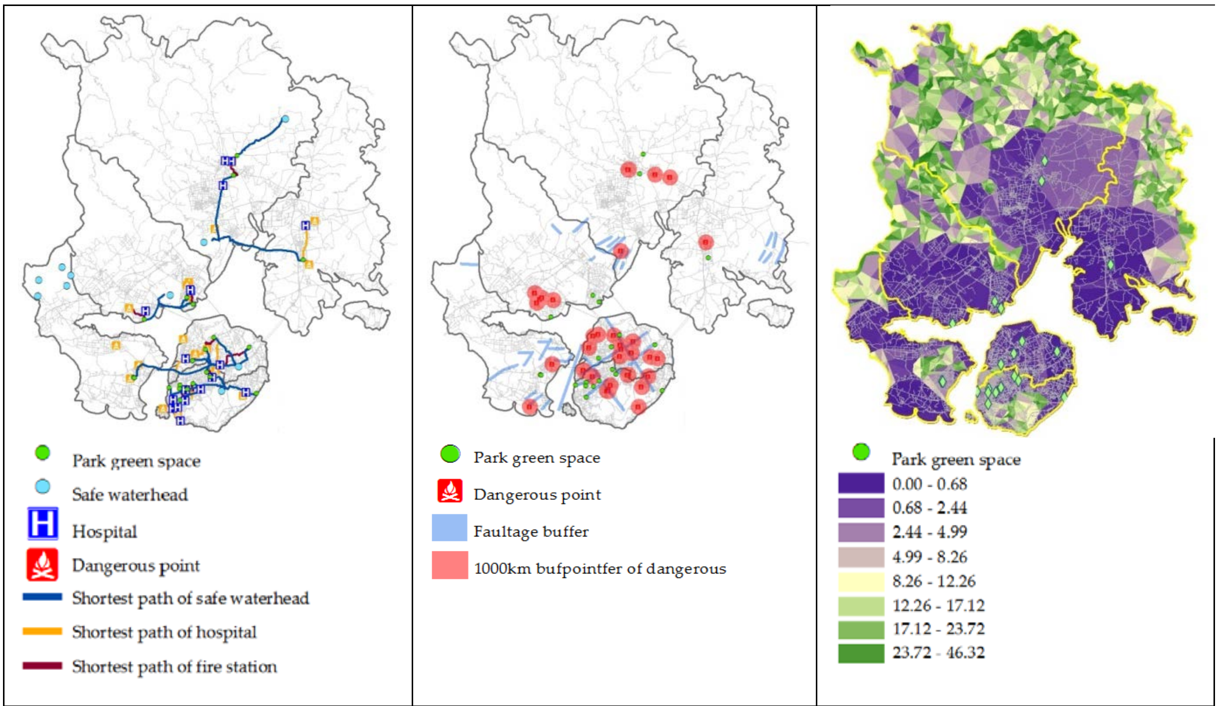
Based on the data collected in the previous section, the Grey correlation of difference factors were generated in TABLE 2 and TABLE 3.

2) Final Results

With the generation of Gray correlation and weight calculated by entropy method (FIG. 3), it was possible to obtain the assessment result of each park green space. In order to understand the suitability of earthquake prevention and refuge of each park green space, this research set three levels of threshold for the decision value. When the value is greater than 0.437, the parks effectiveness is excellent； when the value is between 0.437 and 0.397, the parks effectiveness is good, and when the value is less than 0.397, the effectiveness is moderate.（TABLE 4, FIG. 5）

TABLE 1EVACUATION REFUGE PARK GREEN SPACE IN XIAMEN

Sing Ming District	Zhongshan Park	**Hu Li District**	Songbai Park	**Ji Mei District**	Jingxian Park
	Convention center lawn		Lianhua Park		Jiageng Park
	Jiahe Park		Huli Park	**HaiCang District**	The government green space
			Huoju Park		
	Nanhu Park		Wuyuanwan Park		Arts center green space
	Haiwan Park		Gaoqi Airport green space		
	Hall of the people lawn			**Tong An District**	Dongxi Park
		Ji Mei District	Taiwan-Invested survicecenter green space		Susong Park
	Bailuzhou Park			**Xiang An District**	Xiangwu Park



(a) Shortest Distance to From Park Green Space to Hospital, Fire Station, and Safe Water Source	(b) Dangerous Area Analysis (1000 m buffer)	(c) Gradient Analysis in Xiamen Isalnd

FIG. 2 INDICATOR ANALYSIS

TABLE 2DATA OF SUITABILITY ASSESSMENT

		A1	A2	B1	B2	B3	C1	C2	C3	C4
Jiageng Park	X1	9.725	0.65	2043.61	3034.88	6423.97	2138.2	5973.1	0.131	18
Jingxian Park	X2	11.223	0.47	1141.09	1986.68	6310.94	3260.9	5650.9	0.176	9
Taiwan-Invested survicecenter law	X3	13.8	0.93	1565.78	3012.33	4871.35	2702.5	2189.9	0.097	40
Susong Park	X4	10.55	0.71	2236.15	2690.07	10285.13	8281.9	1551.8	1.133	22
Dongxi Park	X5	7.8	0.58	1249.29	1374.12	8095.05	10750	2712.3	1.034	15
Xiangwu Park	X6	12.34	0.70	4594.52	1717.47	14080.05	6386.6	1977.7	0.038	24
Arts center green space	X7	4.3	0.57	9873.25	750.85	15113.84	1799.2	2037.2	2.256	20
The government green space	X8	16.25	0.75	10167.55	948.00	15408.15	1850.3	1950.8	2.256	20
Zhongshan Park	X9	31.4	0.46	834.31	1477.80	7867.46	0	2758.5	3.251	32
Convention center lawn	X10	49.2	0.69	1620.55	2395.55	5528.69	948.6	2732.4	0.05	27
Nanhu Park	X11	36	0.45	1599.66	2188.27	5757.78	319.4	1007.6	0.669	30
Haiwan Park	X12	87	0.87	1983.45	3781.10	9511.84	0	2073.9	1.891	30
Hall of the people lawn	X13	30.05	0.66	1555.92	2367.28	7844.16	0	1083.1	4.271	30
Songbai Park	X14	12.45	0.29	1459.49	1525.65	4805.04	618.6	2061.2	1.114	14
Lianhua Park	X15	5.8	0.48	294.66	1226.72	4222.79	0	1439.5	1.118	7
Huli Park	X16	28.8	0.51	1293.75	1188.08	6510.67	330.4	1827.5	0.254	34
Huoju Park	X17	9.55	0.27	3556.78	254.43	5921.25	617.6	1136.1	0.127	20
Wuyuanwan Park	X18	109	0.26	5402.57	6572.53	4046.43	135.2	1690.5	0.048	42
Gaoqi Airport green space	X19	9.8	0.61	4475.74	3087.72	5584.69	161.3	795.2	0.134	36
Bailuzhou Park	X20	262.5	0.58	1312.50	2087.64	7661.81	234.4	1445.2	4.271	30
Jiahe Park	X21	10.75	0.41	362.25	1226.12	6243.01	194.8	1259.9	0.669	32

TABLE 3GREY CORRELATION ANALYSIS

	A1	A2	B1	B2	B3	C1	C2	C3	C4
L1	0.341775	0.622768	0.368782	0.353066239	0.574643592	0.384291	1	0.413249	0.46666667
L2	0.34544	0.504379	0.402651	0.364449455	0.582192261	0.417829	0.902621836	0.389381	0.38888889
L3	0.34251	1	0.381152	0.353222744	0.747003213	0.400447	0.441161047	0.451163	0.91304348
L4	0.34007	0.570297	0.365436	0.355765765	0.451844703	0.685316	0.403160161	0.340957	0.51219512
L5	0.344118	0.399715	0.395527	0.380273847	0.499932076	1	0.478050693	0.341705	0.4375
L6	0.337014	0.66711	0.348222	0.369861249	0.412332809	0.551939	0.427752992	1	0.53846154
L7	0.337014	0.426447	0.3401	0.430609632	0.405755188	0.375197	0.431429624	0.337119	0.48837209
L8	0.347682	0.513719	0.3399	0.405971033	0.404078294	0.37654	0.426111274	0.337119	0.48837209
L9	0.362219	0.3951	0.435987	0.376553492	0.507266441	0.333333	0.481612282	0.335951	0.67741935
L10	0.380932	0.449505	0.379313	0.358733869	0.650953513	0.354168	0.479593721	0.675676	0.58333333
L11	0.366876	0.331007	0.379998	0.361342014	0.627175926	0.340069	0.375569822	0.346453	0.63636364
L12	0.427873	0.753817	0.369976	0.348988931	0.465293514	0.333333	0.433729078	0.33786	0.63636364
L13	0.360874	0.437414	0.381499	0.359060601	0.508053913	0.333333	0.379169814	0.335322	0.63636364
L14	0.344217	0.19502	0.385177	0.375028291	0.760018437	0.346631	0.432930586	0.34109	0.42857143
L15	0.338317	0.4397	1	0.386818974	0.922910992	0.333333	0.397139685	0.341062	0.375
L16	0.359638	0.327083	0.393007	0.388848357	0.569156653	0.340306	0.418744698	0.370262	0.72413793
L17	0.341619	0.121044	0.35282	1	0.612275406	0.346609	0.381738469	0.416393	0.48837209
L18	0.460931	0.232873	0.345911	0.342163665	1	0.336152	0.410852713	0.705882	1
L19	0.341841	0.323884	0.348635	0.352708895	0.644792968	0.336701	0.365799288	0.411043	0.77777778
L20	1	0.139683	0.392004	0.36281153	0.514471685	0.33825	0.39744093	0.335322	0.63636364
L21	0.342689	0.172008	0.728236	0.38684921	0.586960007	0.337409	0.38787623	0.346453	0.67741935

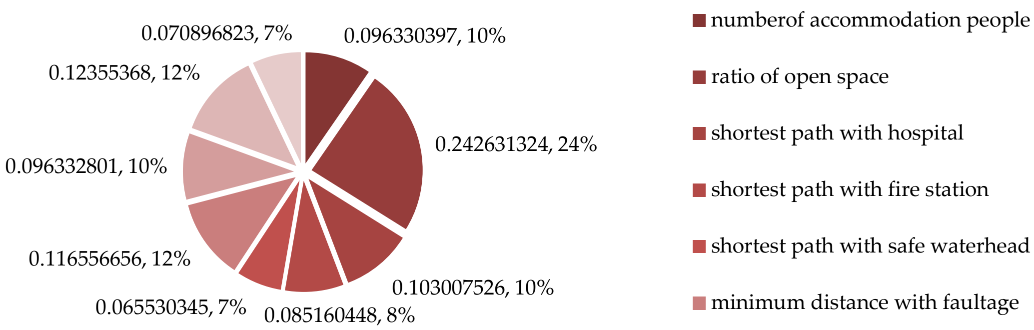


FIG. 3 ENTROPY WEIGHT PIE CHART

TABLE 4 SUITABILITY ASSESSMENT RESULT

	Decision value	Assessment level
Jiageng Park	0.515005536	excellent
Jingxian Park	0.477651761	excellent
Taiwan-Invested survicecenter green space	0.603566762	excellent
Susong Park	0.465835454	excellent
Dongxi Park	0.471864635	excellent
Xiangwu Park	0.555981544	excellent
Arts center green space	0.395795905	moderate
The government green space	0.415414225	good
Zhongshan Park	0.415757214	good
Convention center lawn	0.470358563	excellent
Nanhu Park	0.390406481	medium
Haiwan Park	0.489932524	excellent
Hall of the people lawn	0.405986593	good
Songbai Park	0.356529362	moderate
Lianhua Park	0.481538491	excellent
Huli Park	0.401989068	good
Huoju Park	0.387147984	moderate
Wuyuanwan Park	0.468075087	excellent
Gaoqi Airport green space	0.400127481	good
Bailuzhou Park	0.399470289	good
Jiahe Park	0.38869257	medium

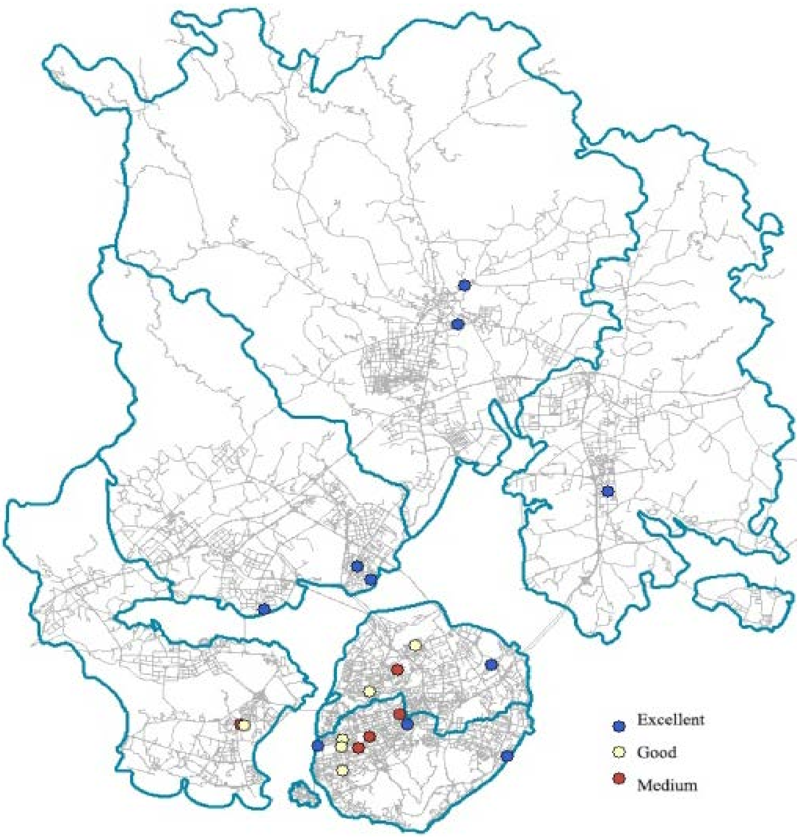


FIG. 4 FINAL SUITABILITY ANALYSIS RESULTS

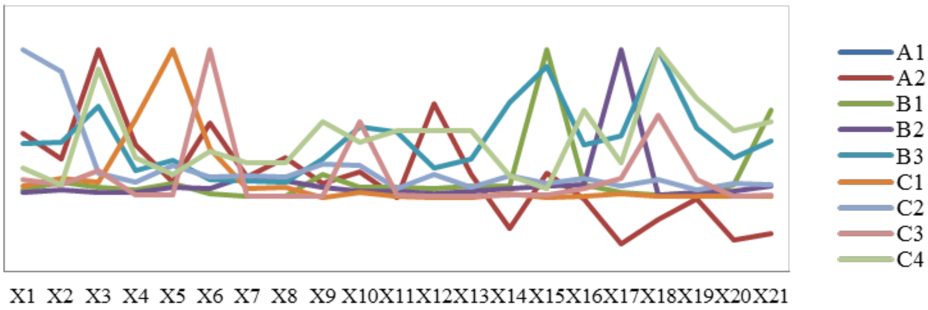


FIG. 5INDEX ANALYSIS OF DISASTER PREVENTION AND REFUGE

Through the suitability result of the park green space, we found the following results:

a)Ten park green spaces received excellent assessment scores distributed evenly in the city of Xiamen. However, Haiwan Park and Lianhua Park are located in the earthquake buffer zone. It will not be able to serve as a good refuge area during earthquakes.

b)Results also showed that four of these twenty-one park green spaces received relatively low assessment score. These five parks are Nanhu Park, Jiahe Park, Huoju Park and Songbai Park. The reason can intuitively derive from the index analysis as below (FIG. 5), water area of Huoju Park is too large, the width of road surrounding Songbai Park is too narrow, Jiahe Park can't accommodate large size of people in a high density area of Xiamen, and the poor accessibility of Nanhu Park also effects its function as earthquake refuge area.

c) We can see most of the green space in evaluation parks are in the island and some of them did not reach the optimal effect, whickis most likely due to the complicated city space structure status. The effectiveness of park green space in Haicang District is relatively low because infrastructure and public service facilities are still being development within this district. With the fast development integration of Ximan Island inside and the outside mainland, the planning and arrangement of park green space outside island would be further improved.

Conclusion

Using GIS, Grey correlation, entropy analysis and based on the criteria of availability, accessibility, and security criteria, this research assessed the suitability of earthquake prevention and refuge shelter transformed from green space in park in the city Xiamen. The result showed that ten, six, and five park spaces can serve as excellent, good, and moderate earthquake refuge areas, respectively. When planning a new refuge area/shelter, availability should be considered firstly and security and accessibility by the general public should be well considered secondly. This paper mainly discussed the prevention and refuge effect of park green space when an earthquake occurred and with the difficulty in collection data, the assessment has some limitations. Cities will be affected by multiple disasters. The assessment should be combined with population distribution and other relevant data in order to reach the optimum efficiency of park green space as evacuation shelter.

REFERENCES

Cheng, J. Urban systems engineering. Wuhan: Wuhan Technical University of Surveying and Mapping, 1999.

GB21734. Earthquake emergency shelter sites and supporting design, 2008.

GB50413. Standard of urban earthquake disaster prevention plan, 2007.

George, H., B. Jane, et al. Introduction to Emergency Management, Butterworth-Heinemann, 2010.

Kakumoto, S., Y. Kosugi, et al. Development of spatial temporal geographic information system and risk adaptive regional management information system - toward development of GIS based on Asian culture for disaster prevention. 2002 SICE Annual Conference, 2002.

Lucien, G. C. Emergency Management: Concepts and Strategies for Effective Programs John Wiley & Sons, 2007.

Perry, R. W., M. K. Lindell, et al. Evacuation planning in emergency management, Lexington Books, 1981.

Wang, J. and J. Zhang "Comparing Several Methods of Assuring Weight Vector in Synthetical Evaluation." Journal of Hebei university of technology 30(2): 54-55, 2001.

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